COM-1 527

MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

FIBER OPTICS, MICROWAVE, AND COAXIAL TRANSMISSION TECHNIQUES

KAMEL M.M. HASSAN*, SAID M.S. SAAD*

ABSTRACT

A comparison study on the three techniques has been done. The study is applied to a particular digital communication link of 280 km length and of 34 M bit/s transmission capacity. It is found that the fiber optic systems are inherently noiser than the others, and the available system gain is much less than it for the microwave and coaxial systems. However, the bandwidth advantage of fiber optics can be utilized through bandwidth expansion techniques to overcome the noise disadvantages. The low loss advantage allows using longer repreater span for fiber optic systems.

The study showed that the optical system is less complex, and the coaxial one comes in the second rank. The estimate cost of the particular link gave that the optical fiber system is the least expensive one, whereas using the coaxial cable led to the most expensive system. For the proposed link, the estimated establishment time for microwave does not exceed 10% over the time needed for the other techniques.

* Assistant Professor, Military Technical College, Cairo, Egypt.

INTRODUCTION

Today, there are several transmission techniques in use. Each has its unique advantages and disadvantages relative to the others. This imposes a difficulty of choices to the system designer for a new system or for upgrading an operating system.

Through this paper, a comparison study on the most commonly used terrestrial transmission techniques (fiber optics, coaxial cable and microwave) is presented. The study is focused on digital communication because of its wide-spread use today. The comparison study will be based on, the noise and bandwidth characteristics of each transmission technique, the complexity, and an economic comparison of each technology. The factors determining the choice of the proper technique are analyzed. At the end of the study, a particular digital communication link has been designed using the three transmission techniques, and the results are compared.

NOISE AND BANDWIDTH CHARACTERISTICS

To quantify the performance comparison, the signal to noise ratio and the bandwidth performance of each technique is given below:

1) Signal to Noise Ratio

The microwave and coaxial cable techniques depend on voltage or current detection, whereas optical systems depend on power detection. The signal to noise ratio $(S/N)_v$ in the systems using voltage detection is given by [1]:

$$(S/N)_v = P_s/(N_{th} + N_{shot} + N_{imp} + N_{flicker}) \qquad (1)$$

where:

P_s = received signal power, N_{th} = thermal noise power, N_{shot} = shot noise power, N_{imp} = impulse noise power, $N_{flicker}$ = flicker noise power.

For photon detection, the signal to noise ratio $(S/N)_p$ is given by:

$$(S/N)_p = i_s^2/(i_q^2 + i_{dark}^2 + i_{preamp}^2) \qquad (2)$$

where:

i_s = detected signal photocurrent, i_q = rms value of the shot noise of the signal (quantum noise), i_{dark} = rms value of the shot noise of the photodetector dark current, i_{preamp} = input referred rms noise current of the photodetector preamplifier.

For well designed systems, the practical limits may be minimized and can be neglected, consequently the fundamental limits will determine the perfomance [2]. The (S/N) ratios for the previous cases in fundamental limits will be given by:

$$(S/N)_v = P_s/KTB_n \quad (3)$$

and $$(S/N)_p = P^2/2h\nu PB_n \quad (4)$$

where:

KTB_n: represents the thermal noise power, K is the Boltzmann constant, T is the absolute temp, and B_n is the noise bandwidth, $2h\nu B_n$: represents the shot noise (quantum noise), h is the Planck's constant, and ν = optical frequency

For voltage detection systems the thermal noise represents the fundamental limit, and the thermal noise power at room temperature for 1 HZ is equal to - 174 dBm. Whereas for optical systems the quantum noise represents the fundamental limit, and it is determined by the detected optical frequency, for example at 1.31 μm wavelength (229 THz) the quantum level is -155 dBm. In practice, the optical system becomes noisily and this makes the noise power of the optical system approximately 30 dB larger than for the conventional systems.

To perform the system gain comparison the signal power available in each system has to be reviewed. For the optical system, the device limitations impose that the maximum available power from the semiconductor injected laser is about 10 dBm. In case of coaxial system, output power is near 20 dBm when transistors are used, the available power is increased by more than 10 dB by using vacuum tubes. In case of microwave systems the use of high power travelling wave tube amplifiers leads to output power that can exceed 40 dBm. The system gain which is defined by the ratio of maximum transmitted power to the allowable minimum received power, may be estimated by using the noise limit and the available power level. The system gain for a typical example of a 45 Mb/s digital system is 103, 90 and 51 [dB] for the microwave, coaxial and lightwave techniques, respectively [1]. This shows that both coaxial and microwave systems have available system gain that is at least 39 dB greater than the lightwave systems.

2) Bandwidth Comparison

The fiber optic system is characterized by unique bandwidth characteristics ranging from moderate band transmission systems (1 GHz) using graded index fibers to very wide-band systems using single mode fibers (several gigahertz). Microwave systems need to efficiently use the available radio frequency spectrum. The bandwidths for available frequency bands are restricted for example, Federal Communication Committee (FCC) in U.S.A. states that the available bandwidth per channel ranges from 3.5 MHz up to 40 MHz according to the frequency band [1]. In addition, the atmospheric disturbances and multipath fading make this a relatively hostile environment for microwave transmission systems. For coaxial systems, the bandwidth is restricted and the system is characterized by the well known $\sqrt{f}$ bandwidth dependence where the attenuation of the cable depends on the square root of the frequency. Fig.1 shows this relaltionship for a typical coaxial cable.

As can be seen from the previous discussion, the optical transmission medium is inherently noise limited, but has a flat bandwidth, whereas the other systems are limited in performance by bandwidth restrictions or distortion considerations, in addition the system gain for microwave and coaxial systems is much higher than for optical one. As a conclusion the system designer prefers the microwave and coaxial systems for the transmission of base-band type analog systems requiring a high signal to noise ratio. On the other hand, the fiber optic system is preferred to transmit for a long span a digital signal with high bit rate requiring relatively small signal to noise ratio.

This can be shown by an example, where a 100 MHz electrical system with an overall system power margin of 104 dB, and the attenuation of 10 dB/km for the used coaxial cable can transmit analog TV signal requiring (S/N) of 55 dB for a moderate distance. On the other hand an optical system of 60 dB power margin can be used to transmit PCM signal for long distance using optical fibers with low attenuation constant, the required (S/N) ratio for this signal is 21.6 dB [3]. The power margin versus repeater spacing of this example is shown in Fig.2. However, the optical analog systems may be used when the fiber is bandwidth limited rather than attenuation limited and to exploit other advantages namely immunity to interferences, lightweight, small size or dielectric isolation. Recently, the improvements in the design and fabrication of semiconductor lasers have resulted in the structures that can meet the strict linearity and noise requirements for multichannel AM - VSB lightwave CATV systems for typical lengths from 10 - 20 km [4].

SYSTEM COMPLEXITY COMPARISON

In comparing the three transmission techniques, it can be shown that the optical system is the least complex one from the point of view of the number of functional blocks required to implement a system. This conclusion is based on the following items:

First, the restricted bandwidths of wirelines and microwave system have led to the use of sophisticated modulation schemes in order to ensure high spectral efficiency. In coaxial systems, unique line codes as ternary line codes 4B3T, 3B2T, and 6B4T [5] are chosen in order to minimize the bandwidth required in a given span to transmit the desired signal. For microwave systems, FM, PM, and hybrid AM/PM, techniques may be used. For example 8-state PSK technique achieves spectral efficiency of 3 bits/Hz and the 16-QAM technique achieves 4 bits/Hz. There are higher order modulation schemes such as 64-QAM and 32-PSK which achieve even higher spectral efficiencies [6]. In contrast, fiber optic system which is characterized by high bandwidth uses very simple on-off keyed modulation scheme, this scheme is spectrally inefficient.

Second, the coaxial transmission system requires relatively sophisticated equalization circuitry to compensate for fluctuations of its high loss as a function of temperature and other parameters. On the other hand, the optical system requires no such equalization because of its flat bandwidth characteristics. For microwave system,sophisticated devices and functions are required, where predistortion and adaptive equlization are required in high performance systems to compensate for anomalies in the output stages and transmission path. For high spectral efficiency, it also requires additional complexity in the ways of filtering, equalization, and higher order modulation schemes whereas these techniques are not required for optical systems.

Third, for optical fiber systems the terminals are spaced at further distances than the other two techniques especially when 1.55 microns operating wavelength is used. This reduces the number of used repeaters for achieving a certain communication distance. In contrast, the coaxial systems of high attenuation need more repeaters to achieve the same link. For microwave, the repeater station is more complex than the optical fiber one.

SYSTEM ECONOMICS COMPARISON

The relative cost of any technique will vary depending on the exact circumstances. To perform the economics comparison, we have to consider several factors:

i) Equipment type consideration: the most important parameters of the transmission system equipment to be compared are the bandwidth and the span length. Since the fiber bandwidth is higher than the bandwidths of the other techniques, so its cost degradation is tangential at higher bandwidth needed. The optical fiber system can offer economical large capacity long haul transmission because of (a) It has long repeater spacing, (b) Several hundreds of optical fiber can be accomodated in a single cable duct, whereas maximum tube number is limited in coaxial cable, and (c) The fiber material cost is relatively cheap and plentiful than the copper. The fiber cost is increased for low loss fiber, this dependence is shown in Fig.3. For design, a compromise between the required attenuation per km and the cost of fiber has to be done [7].

ii) Signal type cost consideration: this takes into account the signal processing part: (a) The optical system requires the same multiplexing equipment as for microwave and coaxial systems, but it is advantageous in that it does not need fading correction as the microwave needs, nor equalization as in coaxial cables. For high capacity the multiplexing equipment cost predominates over the transmission medium, (b) For optical and microwave systems, it is optimum to use local stabilized power supply to feed the repeaters than using costly unreliable remote power supply as in the case of coaxial system, this is due to the greater repeater span achieved by the previous systems, (c) Supervisory and monitoring equipment of the optical system are more expensive due to the high bandwidth and high required performance.

iii) Establishment cost considerations:these include: (a) The cost of components which depends on the manufacturer, (b) The installation cost; where the lightweight and small size of fibers lower the installation cost relative to coaxial cables, (c) Maintenance, the maintenance of fiber optic system is much less expensive than that of the coaxial and slightly lower than that of microwave, (d) Operational cost, this includes the inventory cost of spare parts to be maintained, the fiber system is still most expensive one.
(e) Right of way, generally the optical fiber system may find suitable right of way at a cost lower than in coaxial, (f) Cost of money, in coaxial cable it is difficult to expand the channel capacity because the cable equalization and repeater spacing are dependent on the used bit rate, for microwave the expansion is limited by the frequency spectrum available, in optical system the expansion is easy, where it is achieved by replacing the electronic equipment only.

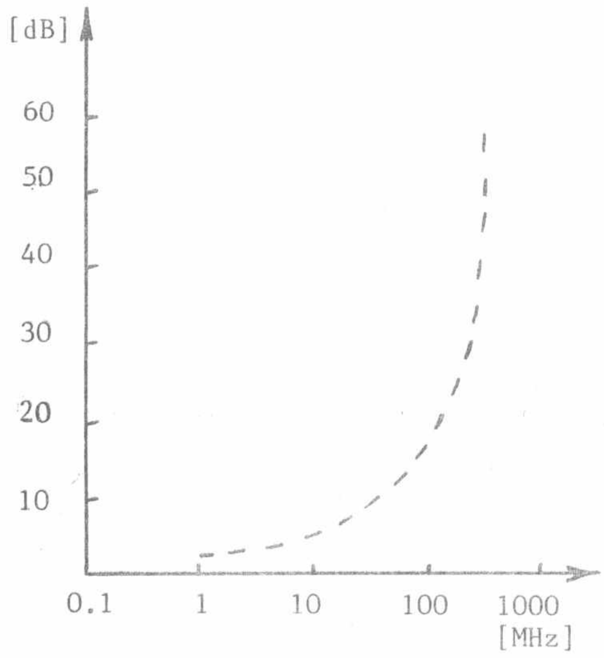

Fig.1. Attenuation of coaxial cable (9.5 mm).

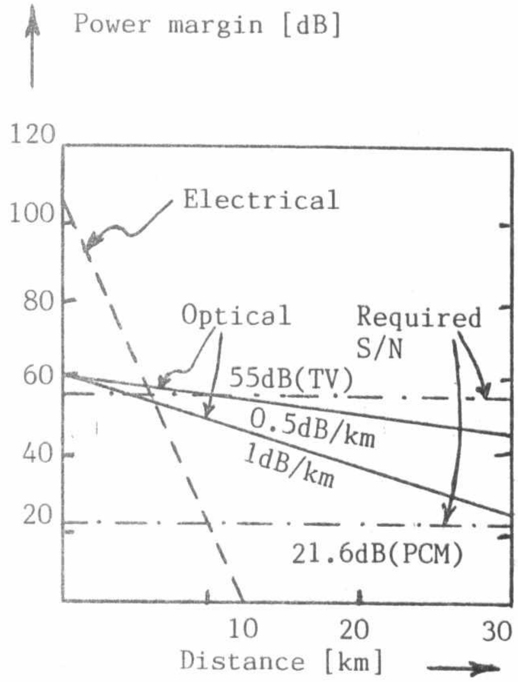

Fig.2. Power margin versus repeater spacing.

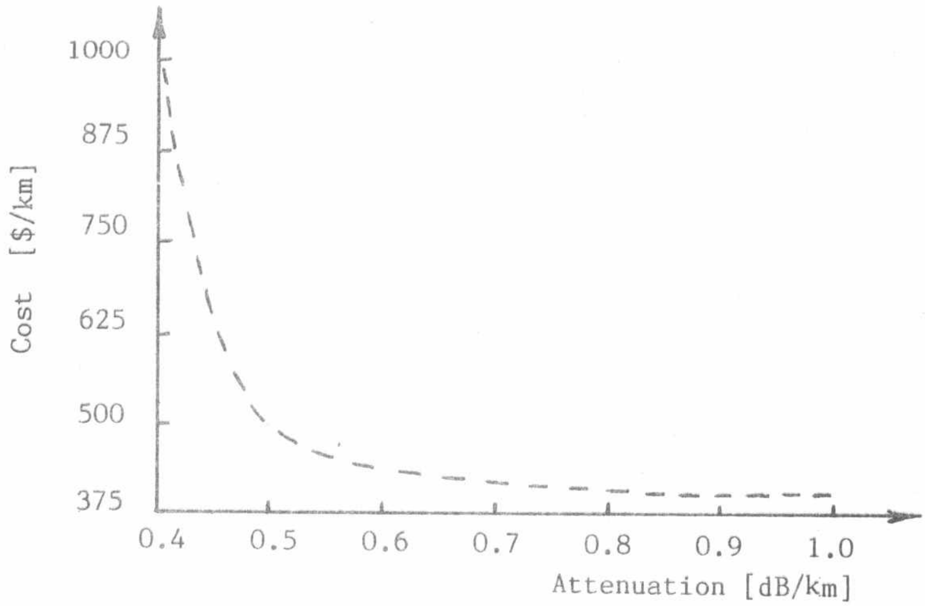

Fig.3. Cost of fiber versus attenuation

THE CHOICE OF THE PROPER TECHNIQUE

One major decision that the transmission system engineer often faces is whether to use one of the previous transmission techniques on a particular point-to circuit. The factors determining the choice fall into two categories: technical and economic. Table 1 summarises the comparison of the three techniques. In addition to the mentioned items in the table, the optical fibers are characterized by small size, light weight and rugged physical properties. From the previous comparison, we can understand the motives of the telecommunication system planners to use the fiber optics in many applications. Optical systems are rapidly supplanting microwave and conventional cables in connections between telephone switching offices. In addition, the fiber technology is introduced gradually to the existing cable television networks which are based on coaxial cables in order to improve the performance and to achieve future bandwidth increase [4]. However, the microwave system has to be chosen in a particular application where the terrain is difficult or when the establishment time is critical or when the deployment is necessary.

PARTICULAR SYSTEM COMPARISON

A particular digital communication link of distance 280 km is designed to carry 480 voice channels. The channels are multiplexed to the third order level of the CCITT heirarchy, (34 Mbit/s) based on pulse code modulation (PCM). The permissible bit error rate (BER) is required to be less than 10^{9}. The three transmission techniques are used to design this particular link. First, the routing is examined, this gives that the link will suffer from multipath fading. Second, the calculation of the link for each technique has been done. Third, the cost of the link in each case has been estimated.

For fiber optic link operating at 1.3 micron wavelength, flux budget and rise time budget have been examined for the proper choice of the components. The fiber attenuation is o.5 dB/km and the splice loss is o.25 dB per splice. These gave that the span length is 56 km and the system can support the required bandwidth. Optical cables containing 4 single mode fibers; two for the operating link and the other two for the future expansion had been chosen. The cost estimation is L.E. $3.8x10^{6}$ including the fiber cable, the line terminal unit, the repeaters, the set of batteries, and the digging cost.

For the microwave link, special radio set (CTM-250) had been chosen, the span length is estimated to be 45 km, the space diversity technique is used in order to avoid multipath fading. The estimation cost for the microwave link is L.E. $6.5x10^{6}$. This sum includes the costs of: radio stations, the switching units, power supplies, set of batteries, the antennas, the towers, and the encryption sets.

For coaxial cable link using 9.5 mm cable, the design gives that the required number of repeaters is 67 dependent amplifiers (DA) + 2 main repeaters where the main repeaters and the two terminals feed power to DA'S. The cost estimation of the coaxial link included the price of 4 coaxial tube cables (2 + 2 spare), line terminal equipment, remote power supply for repeaters, encryption sets, and digging cost. The cost of the link is L.E.$13x10^{6}$.

Table 1. Comparison of The Three Transmission Techniques

Ser. No.	I t e m	Fiber Optics	M i c r o w a v e	C o a x i a l
1	2	3	4	5
1.	Land acquisition.	Required right of way along entire route and recurring maintenance access later.	Repeater site acquisition.	The same as for fiber optics.
2.	Terrain.	Important consideration in cable laying.	Can jump over, and even take advantage of difficult terrain.	The same as for fiber optics.
3.	Repeater span.	It depends on the used wavelength and the transmitted bit rate (up to 70 km).	It depends on drop and insert requirements as well as economic trade off between tower height and hop distance (30-60 km).	It depends on the highest frequency to be transmitted (1.6, 4.5, 9 km) [8].
4.	Insert and drop.	At more widely spaced repeater sites.	At repeater sites.	At any repeater, should be kept minimum.
5.	Multiplex.	TDM - CCITT.	TDM - CCITT.	TDM - CCITT.
6.	Radio frequency interference.	N o n e.	A major consideration.	A minor consideration.
7.	Fading.	None except temperature variations.	Important engineering parameter.	None except temperature variations.
8.	Security.	Highly secured.	Not secured.	Less secured.
9.	Available system gain.	Low (~ 60 dB)	High (more than 100 dB).	High (more than 90 dB).
10.	Information bandwidth.	H i g h.	Limited by FCC rules.	Limited by cable loss.
11.	Power considerations.	Low voltage dc in mA range at each site.	48 V dc at each site in ampere range [8].	High - voltage dc in mA range.
12.	Expandability.	E a s y.	Restricted.	D i f f i c u l t.
13.	Comparative cost of repeater.	L o w.	H i g h.	L o w.

Table 2. System Parameter Comparison

parameter \ system type	Fiber optics	Microwave	Coaxial
System gain	50 dB	104 dB	90 dB
Repeater span	56 km	45 km	4 km
Modulation technique	OOk	F S K	4 B 3 T
Relative cost	1	1.7	3.4
Bandwidth	60 MHZ	30 MHZ	13 MHZ
Relative establishment time	1	0.07	1.1

Table 2 summarises the main parameters of the 34 Mbit/s system for the three techniques. The comparison states that the optical system is characterized by highest repeater span, lowest cost, and the possibility of future expansion to carry more information. In addition, for special requirements, the microwave and coaxial cable systems need encryption sets to ensure secured communication whereas the optical system provides secured link without encryption. As the technology is advanced, the third generation using 1.55 microns wavelength and the dispersion shifted fibers will be costly effective. Consequently, the available repeater span will be much larger and carrying huge bandwidth.

CONCLUSION

The comparison study showed that the fiber optic technique presents unique advantages particularly for digital communication at high bit rates. However, the microwave technique is indespensable because of its unique features over cable - based systems, where it is used for difficult terrain, and it does not require right of way. In addition, the microwave system is preferable for quick establishment and when the deployment has to be performed at small time intervals. On the other hand the coaxial cable technique is relatively costly and the span length is relatively very small compared to the other techniques. In addition, the coaxial systems are relatively complex as compared to the fiber optic ones. The analysis and calculations of the particular link using the three techniques have assured the previous conclusions.

As a final conclusion, the fiber optics and microwave techniques are complement, whereas the coaxial cable usage is decaying, and the upgrading process of the present communication networks uses the optical fiber instead of the coaxial cables.

REFERENCES

1. Jones, J.R., "A Comparison of Lightwave, Microwave and Coaxial Transmission Technologies", IEEE Journal of Quantum Electronics, Vol. QE-18, No.10, 1529-1535 (1982).
2. Personik, S.D., "Fundamental Limits for Optical Communication", Proc. of IEEE, Vol.69, No.2 (1980).
3. Gowar, J., "Optical Communication Systems", Prentice Hall International, Inc., London (1984).
4. Large, D., "Tapped Fiber vs. Fiber Reinforced Coaxial Systems: A Comparison of Evolutionary Paths", IEEE Lightwave Communication System Magazine, Vol.1, No.1 (1990).
5. Reeves, H.S.V., "140 Mbit s^{-1} Digital Line System for Coaxial Cable", Electrical Communications, Vol.53, No.2 (1978).
6. Oetting, J., "A Comparison of Modulation Techniques for Digital Radio", IEEE Transactions on Communications, Vol. Com. 17, No.12 (1979).
7. Misra, R.B., "Loop Optic Design Optimization Study", IEEE Journal on Selected Areas in Communications, Vol. SAC-4, No.5 (1986).
8. Freeman, R.L., "Telecommunication System Engineering Analog and Digital Network", John Wiley and Sons, Inc., New York (1980).